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SUBJECT: Space Shuttle Launch of  
Large Payloads and In-Space  
Stages - Case 105-3

DATE: September 25, 1969

FROM: H. S. London  
D. Macchia

ABSTRACT

The second stage of a fully reusable two-stage Space Shuttle could be replaced with a high mass fraction propulsion module which is not designed to reenter the atmosphere and land. The combination of the Space Shuttle first stage plus the propulsion module would be capable of boosting on the order of 100,000 lbs or more payload, depending on the nominal Space Shuttle capability, to low earth orbit. In addition, the propulsion module could be used in space as a reusable interorbital shuttle for lunar and geosynchronous missions and also for manned planetary missions.

This approach would permit elimination of the Saturn V from the manned space flight program, replace the nuclear shuttle with the chemical propulsion module, and would tend to size the Space Shuttle for smaller payloads (say, 25,000 lbs) versus the present nominal 50,000 lbs.

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MEMORANDUM FOR FILE

Introduction

One of the chief limitations of current concepts for reusable integrated launch and reentry vehicles (Space Shuttle) is that their limited payload and volume capability forces continued use of Saturn V derivative launch vehicles. The baseline Space Shuttle with 50,000 lb payload and 15 ft diameter by 60 ft length payload volume capability permits launch of payloads such as logistics cargo, propellant, satellites, small stages, etc. Large in-space stages, such as a nuclear stage for lunar or planetary missions, or payloads greater than 50,000 lb exceed shuttle capabilities. Development of a larger shuttle to meet these occasional requirements appears uneconomical due to the higher development and operational costs.

However, it is possible to replace the second stage of a fully reusable Space Shuttle by a relatively high mass fraction  $H_2/O_2$  stage which is not designed to reenter the atmosphere and land (Reference 1). This stage could serve as a multi-purpose propulsion module and would add a great deal of mission flexibility to the Space Shuttle. Used simply as a high performance second stage, it could be used to boost the occasional large payloads into low earth orbit which are too heavy to be carried on the two-stage Space Shuttle. Alternately, the propulsion module can be used to boost itself into earth orbit partially fueled, where it can be refueled by multiple flights of the Space Shuttle. If multi-start capability and adequate meteoroid shielding are provided, the propulsion module can then be used as a reusable in-space stage for interorbital shuttle, lunar and geosynchronous missions, thereby replacing the nuclear shuttle. It can also be used in place of the nuclear shuttle or stage for manned planetary missions.

Once the two-stage shuttle and this optional propulsion module are in operation, the Saturn V would no longer be required in the Integrated Manned Space Flight Program (Reference 2).

### Configurations

There are several options for the propulsion module. It could range in complexity from a modified SIVB stage to a completely new stage optimized for mission requirements and shuttle first stage characteristics. Another option would be to utilize the shuttle second stage propulsion and structural systems as much as possible to achieve some degree of commonality between the two stages.

The SIVB option offers minimal development costs, but without extensive modification only meets the requirement to boost occasional large payloads into low earth orbit. This option has been discussed briefly in Reference 3 and is under further study.\* Non-reusability, lack of capability for long duration  $LH_2$  storage, and low performance make it undesirable for interorbital, lunar, geosynchronous, or planetary missions. Discussion of a completely optimized propulsion module is beyond the scope of this memorandum. Rather, a new propulsion module with a gross weight including payload equal to that of the Space Shuttle second stage is assumed. This is compatible with the use of common engines for the Space Shuttle second stage and propulsion module, and allows us to assume launch trajectories and  $\Delta V$  requirements which are essentially identical to those of the Space Shuttle.

Figure 1 illustrates the booster element of a 50,000 lb payload Space Shuttle configuration studied by General Dynamics (Reference 5) with either the orbiter stage or a propulsion module. Both the orbiter stage and PM have similar aerodynamic contours and some commonality of structural and propulsion systems. Over 30,000 ft<sup>3</sup> payload volume is available after provision for PM propellant tankage.\*\* (The tankage volume indicated is for 720,000 lb propellant which corresponds to  $\lambda = .88$ .) It is also possible to utilize this payload volume for a larger PM. This alternative would result in a higher mass fraction stage of 1,300,000 lb propellant capacity which would have to be launched offloaded.

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\*Martin Marietta has also suggested the possibility of launching a nuclear stage or a hydrogen tanker with an expendable Space Shuttle second stage (Reference 4).

\*\*Unpublished configuration analysis by A. S. Kiersarsky.

### Payloads

The payload capability of representative  $H_2/O_2$  propulsion modules, boosted by the first stage of a two-stage Space Shuttle, varies with shuttle configuration. The following figures are based upon interim Space Shuttle study results reported by General Dynamics for a two stage, sequential burn Space Shuttle (Reference 5). For a 50,000 lb payload Space Shuttle the PM has a gross weight of about 817,000 lbs, and for a 25,000 payload Space Shuttle the PM gross weight would be about 520,000 lbs. In computation it was assumed that the gross weight of the propulsion module is equal to the second stage plus payload weight of the Space Shuttle. When launching large payloads rather than just the PM itself, the propulsion module is offloaded so that its launched weight plus payload weight equals the Space Shuttle second stage plus payload weight. The PM mass fraction was assumed to be .88 and the specific impulse 460 sec. The Shuttle first stage plus PM would then be capable of launching payloads of about 171,000 lbs and 108,000 lbs respectively (for the two shuttle sizes) to a 270 nm, 55° inclination orbit. This includes a reduction of 500 fps in the on-orbit  $\Delta V$  budget to allow for the fact that the PM, as compared with the Space Shuttle second stage, does not retro to reenter the atmosphere.

### Typical Missions

The large propulsion modules (817k and 520k) derived from the 50k and 25k shuttle second stages offer considerable payload and mission capability. In the following paragraphs some typical missions are discussed to illustrate this potential.

#### Lunar Missions

Figures 2 and 3 illustrate the lunar orbit mission capability of a shuttle-boosted propulsion module. Figure 2 shows the outbound and return payload capability of a PM (either the 50k or 25k shuttle sizes) to a highly elliptical lunar orbit. The elliptic lunar orbit mode is a way of increasing the performance and reducing the performance sensitivities of a chemical interorbital shuttle (Reference 6). By reducing the interorbital  $\Delta V$  required while increasing that of the lunar orbit to lunar surface stage or LM-B (LM-B described in Reference 2) the overall result is a better distribution of  $\Delta V$  between the interorbital shuttle and the LM-B. The LM-B would have to grow to approximately 85,000 lbs to have the same payload capability from elliptic orbit as a 50,000 lb LM-B from circular orbit.

The smaller sized PM can carry about 135,000 lbs to the elliptic lunar orbit and return 10,000 lbs, which is adequate for a LM-B and Space Station Module out and a Crew Return Module back. The larger sized PM greatly exceeds this in payload capacity.

Two ways of utilizing the smaller (520k) PM in a two-stage configuration to go to a low altitude circular lunar orbit and return are shown in Figure 3. The lower curve which is for parallel staging, where both stages are operated together throughout the mission, shows a capability of 100,000 lbs out (LM-B plus Space Station module) and more than 10,000 lbs back. The upper curve is for a series staging mode in which the first stage boosts the second stage plus payload to several thousand fps above circular earth orbit speed and then returns itself to low earth orbit. The second stage completes the translunar injection, carries out lunar orbit insertion, trans-earth injection, and returns into low earth orbit. With this mode the payload capability is more than double that with parallel staging.

#### Planetary Missions

The PM can also be used in place of nuclear stages for manned planetary missions. The use of 520k PM's for the 1981 Mars landing Venus swingby mission is illustrated in Figure 4. Starting from a highly elliptical (approximately 24 hour period) earth orbit, two PM's are required for the spacecraft shown and for  $\Delta V$ 's based on an 80-day stay time in a 13.5 hour period elliptic orbit at Mars (Reference 7).

The first PM boosts the spacecraft plus second PM out of earth orbit onto the trans-Mars trajectory, and later is restarted to provide the first 2,000 fps  $\Delta V$  of the Mars capture maneuver. After the first PM is jettisoned the second PM completes Mars capture and 80 days later carries out the Mars escape burn. Finally, at earth return, the second PM retards itself and the Crew Return Module into a highly elliptical earth parking orbit from which they can be brought down to low orbit by an earth orbit based PM.

Two alternatives are available for boosting the spacecraft and two interplanetary PM's up to approximately a 24 hour elliptic earth orbit (Figure 5). In either mode no additional PM's are expended.

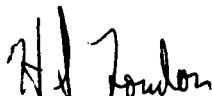
In the first mode, the spacecraft and interplanetary PM's are assembled in low orbit with a cluster of 3 PM's for boost to the highly elliptic orbit. Two of the PM's are ignited first and after reaching a speed of about 5,300 fps above low altitude circular speed are jettisoned and deboost themselves back to the low altitude orbit. The center PM of the cluster of 3 is then ignited and completes the boost to the 24 hour elliptic orbit; it then deboosts itself back to low circular orbit.

The alternative mode is to use a single PM as an interorbital shuttle, rendezvousing the interplanetary spacecraft and PM's in the highly elliptical orbit. Four shuttle trips from low circular orbit to the highly elliptical orbit are required: one to bring up the complete spacecraft, two to bring up offloaded PM's (approximately 150,000 lbs of propellant offloaded), and one to carry the remaining propellant required for the two PM's.

#### Summary and Observations

A high mass fraction propulsion module which is capable of launching itself to earth orbit after initial boost by the first stage of a reusable Space Shuttle offers the following advantages:

1. Large occasional payloads exceeding Space Shuttle capability can be launched to earth orbit thereby eliminating any requirement for a Saturn V class launch vehicle.
2. Such a PM would be of sufficient size and performance to be suitable for interorbital shuttle, lunar, geosynchronous orbit, and planetary missions and would eliminate any requirement for nuclear stages or shuttles.
3. Use of a PM plus shuttle first stage mode for launching large payloads tends to permit sizing the Space Shuttle for smaller payloads (25,000 lbs, for example). The smaller shuttle would have lower development and operational costs.

  
H. S. London

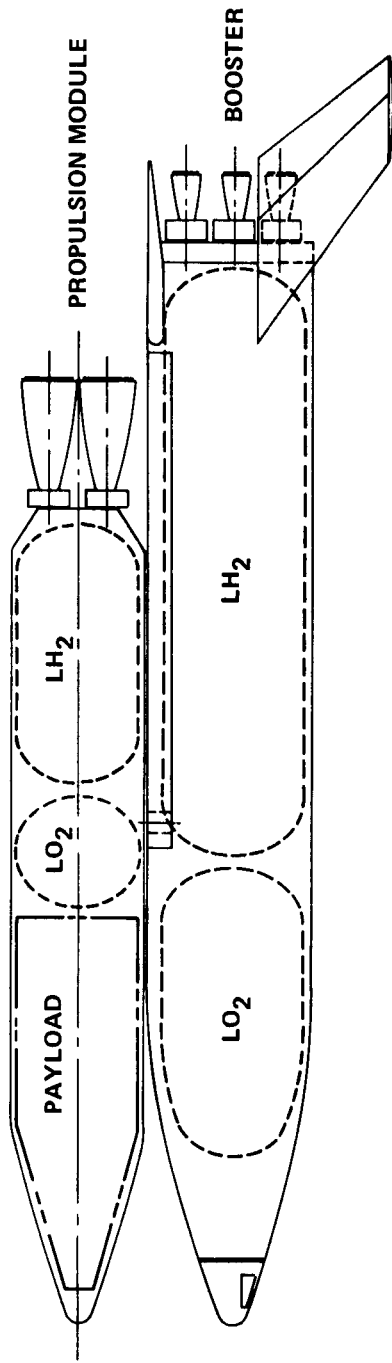
  
D. Macchia

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171,000 LB PAYLOAD LAUNCH VEHICLE CONFIGURATION



50,000 LB PAYLOAD IRLV CONFIGURATION

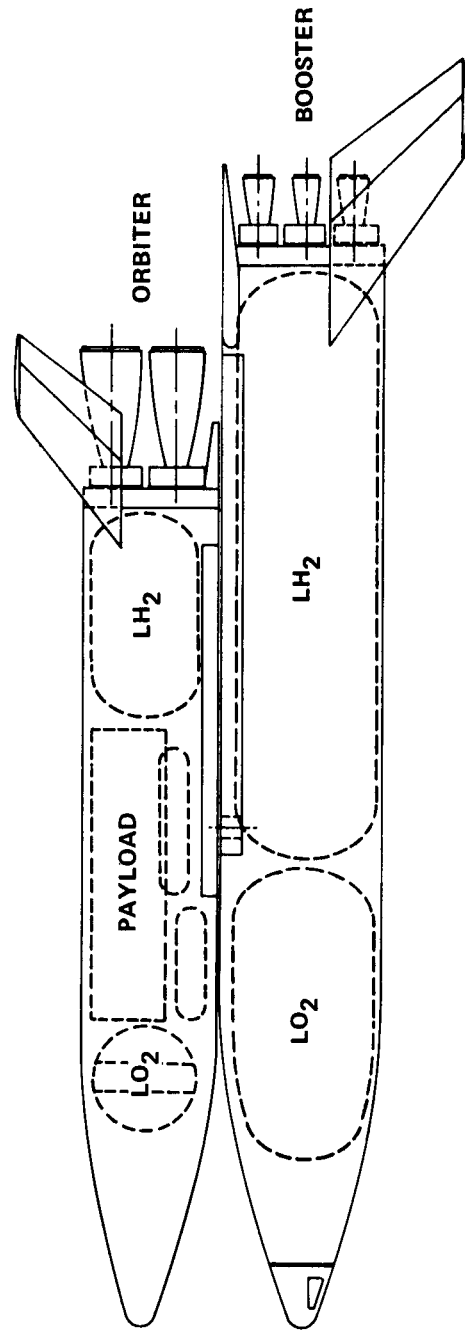


FIGURE 1



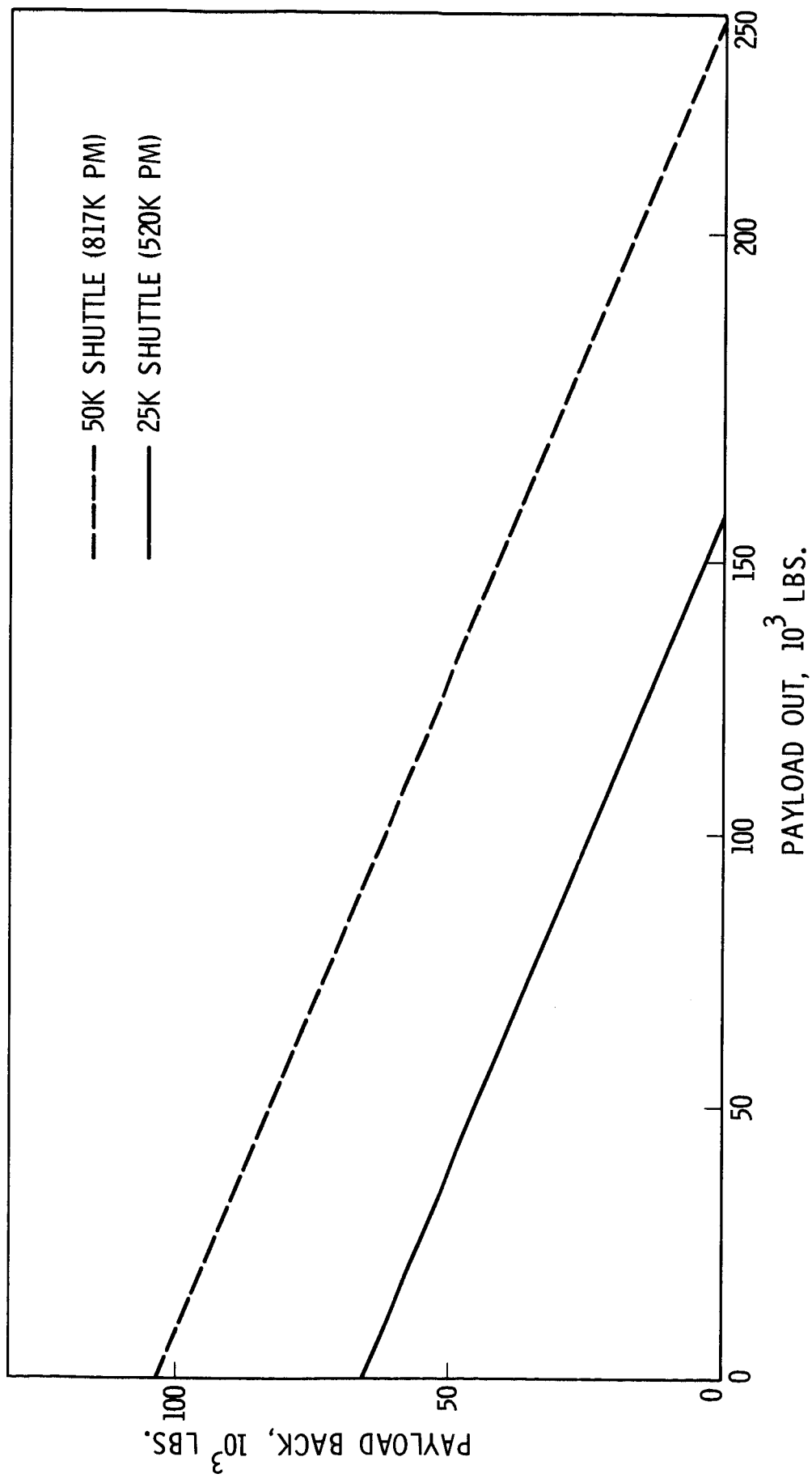


FIGURE 2- LUNAR ORBIT CAPABILITY (ELLIPTIC LUNAR ORBIT)  
SHUTTLE BOOSTED PROPULSION MODULE

$I_{SP} = 460$  SEC.  $\lambda = 0.88$

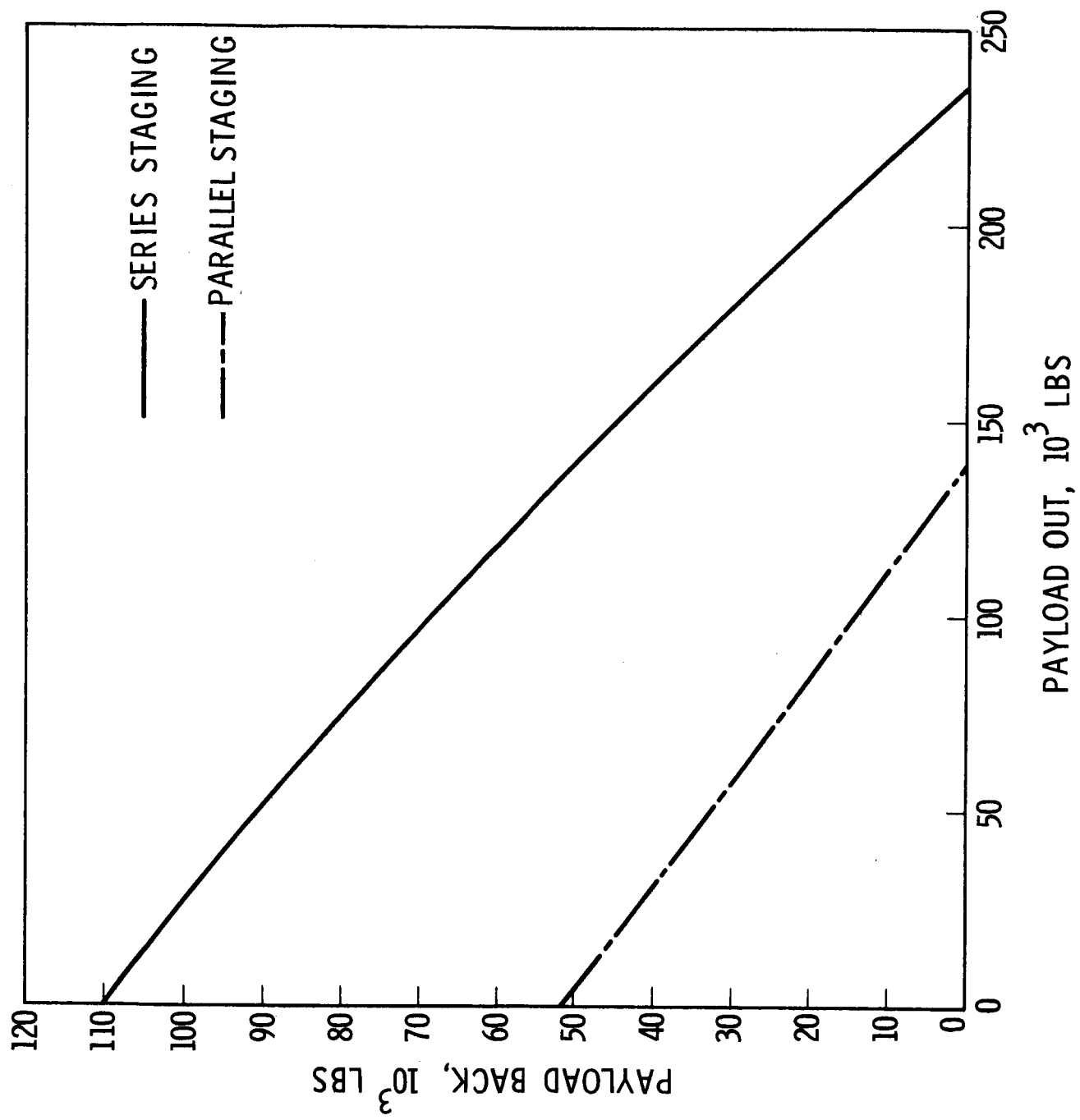


FIGURE 3- LUNAR ORBIT CAPABILITY (CIRCULAR LUNAR ORBIT)  
TWO 520K  $H_2/O_2$  STAGES

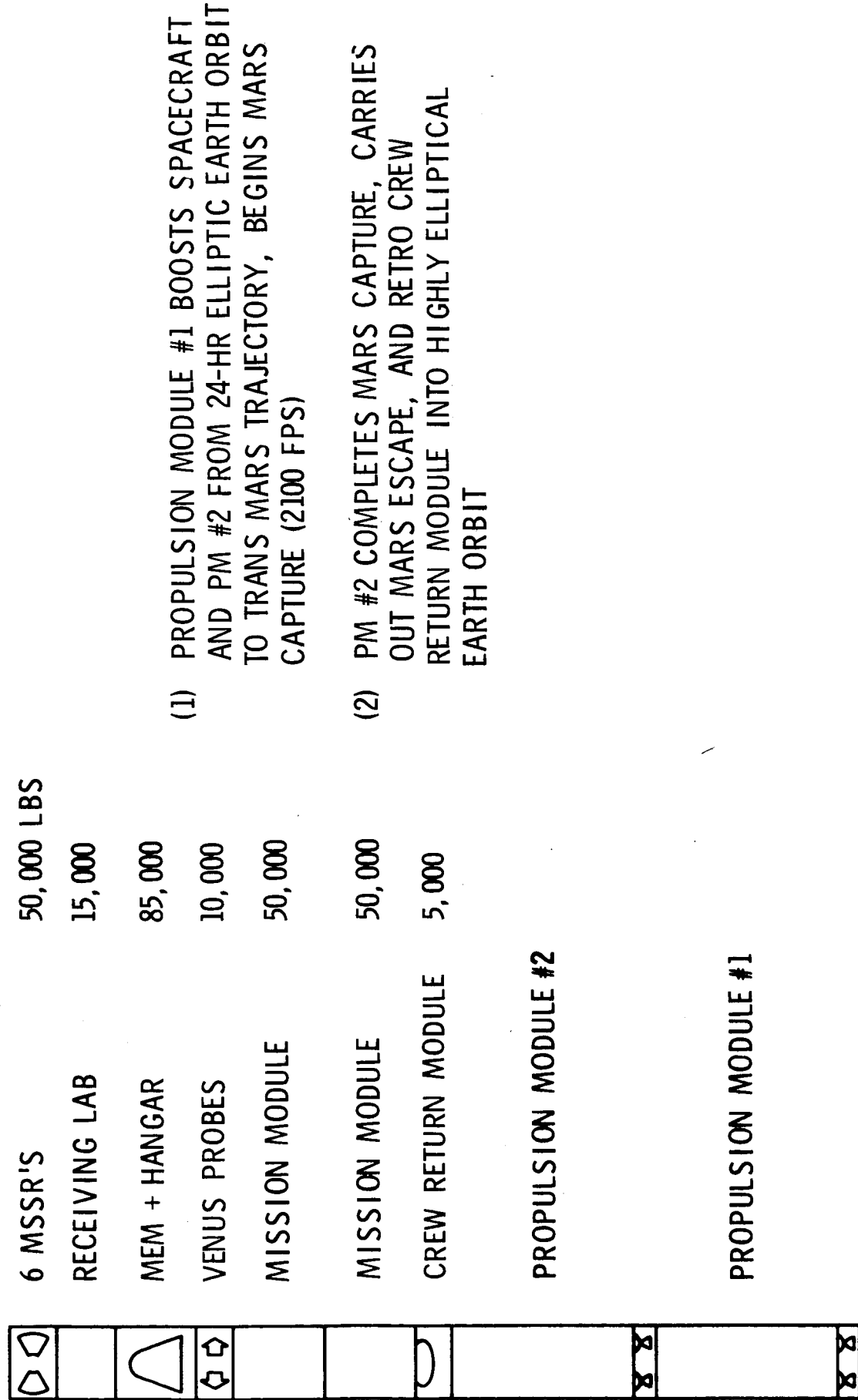


FIGURE 4- MARS LANDING VENUS SWINGBY MISSION WITH SHUTTLE BOOSTED PROPULSION MODULES

### OPTION A

- (1) RENDEZVOUS AND ASSEMBLY IN LOW ORBIT
- (2) CLUSTER OF 3 PM'S BOOST S/C + 2 INTERPLANETARY PM'S INTO 24-HR ORBIT
- (3) 3 PM'S DEBOOST BACK TO LOW EARTH ORBIT

### OPTION B

- (1) CHEMICAL SHUTTLE (= PM) CARRIES S/C TO 24-HR ORBIT
- (2) CHEMICAL SHUTTLE BOOSTS OFF LOADED PM #1 TO 24-HR ORBIT
- (3) CHEMICAL SHUTTLE BOOSTS OFF LOADED PM #2 TO 24-HR ORBIT
- (4) CHEMICAL SHUTTLE CARRIES REMAINING PROPELLANT REQUIRED TO PM'S #1 & #2, RETURNS TO LOW ORBIT
- (5) RENDEZVOUS & ASSEMBLY IN 24 HR ORBIT

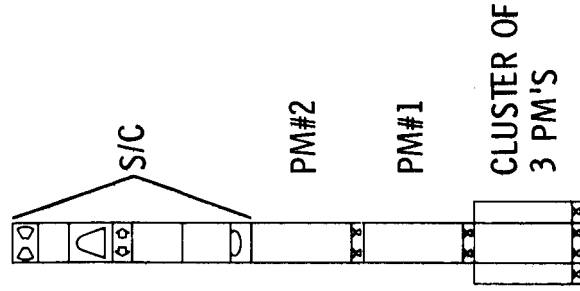


FIGURE 5- BOOST FROM LOW EARTH ORBIT INTO 24-HR ELLIPTIC EARTH ORBIT